<u>Annual Technical Progress Report (End Year 1)</u>

Robust Localization, Classification, and Temporal Evolution Tracking in Auroral Data

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1   Introduction

This report is a summary of the progress for the first 12 months of effort on the AISR award NNG-05-GA88G. The project officially began on October 15, 2004 and was scheduled to end on October 14, 2005. The project is currently in a no-cost extension, thus the current report is an annual report rather than the final report. We note that this report is late due to a misunderstanding relating to whether only a final report would be required on the project if the project went into an extension period. We apologize for our misunderstanding and for the delay in submission of this report that it entailed.

1.1   Problem Background

The NASA Polar mission's UVI sensor produces nearly 2,350 images per day. The sensor has been in operation since 1996, producing over 8 million images in all. The huge number of images presents excellent opportunities for study of auroral phenomena but also presents challenges in finding the images of most interest for a particular investigation. To aid in the task of finding images of interest, Co-I Germany has developed the On-line Search Tool, an interface to the database of UVI images. The tool allows retrieval of images based on time of collection and some simple auroral features. Various methods were developed previously and incorporated into the tool to allow mining of images and image meta data for the supported search keys. However, the current tool's capabilities are limited by the challenging nature of the images, including high levels of noise, low contrast, and stars in some images. In addition, presence of day glow in many images can confuse the methods used by the tool's image miner.

1.2   Project Components

The project we report on here has three components, all related to development of algorithms that will allow more reliable automated detection of auroral arcs in NASA Polar UVI images. The project's ultimate goal is to allow tje existing On-line Search Tool, which was developed under support of the AISR program, to exhibit enhanced image retrieval capabilities. The three components being tackled are aimed at supporting that larger goal. The three components are described next.

1.2.1   Improved Component Isolation

The first component involves improving the performance of an existing k-means-based semi-automated method for isolating auroral arc features (e.g., pieces/components of the auroral arc) from background

in NASA Polar UVI images.

1.2.2 Forming a Coherent Arc

The second component involves developing a method (or methods) that automatically allow a coherent auroral arc to be localized in a UVI image, such as by joining small components of the arc into a unified whole without also joining non-arc components. The primary means to be investigated was shape-based processing via use of the Hough transform. Such mechanisms will tend to produce extracted forms that are exactly or nearly exactly elliptic in shape.

1.2.3 Refinement of Arc Description

The third component involves exploration of so-called active contour-based approaches in conjunction with the shape-based processing steps developed in the second component of the project. Efforts on the third component were to be quite modest for this project.

2 Brief Progress Summary (Results to Date)

In this section, the progress on the project is briefly summarized. Many low-level details have been omitted; our aim is to provide a fairly high-level summary of progress.

During the first year of work, we focused on the first and second components of the project.

2.1 K-means-based Methods

The SPSU sub-team, led by Co-I Hung, conducted experiments to help establish the qualitative performance of the k-means-based auroral arc segmentation scheme that they had developed previously. They also worked on means to improve the k-means approach.

One emerging outcome is related to a study of the competing means to localize the auroral arc. Since no comparative study of the performance of the k-means method for auroral oval segmentation versus the other existing methods ([1], [3], [4]) had ever been compared, we began gathering results for a comparison study. The study will conclude shortly, and we aim to write a paper summarizing its findings. Preliminary indications are that the k-means-based approach has roughly comparable performance versus other existing approaches, but none of the approaches are really suitable for use in an automated system. (The work we describe related to the second component of our project is aimed at addressing that problem.)

2.2 Progress in Forming a Coherent Arc

The major effort during the year was the development of an approach for automatically locating the complete auroral arc in UVI imagery. The approach is shape-based.

First, we established that the shape of the oval in UVI images should be elliptic. This finding is based on prior work in the field (e.g., [2, 5]). That work determined that in 3D space, the auroral oval is a circle, or at least is well-approximated by a circle. Since UVI's image is actually a projection of the auroral oval from real space onto the image plane, that projection can be proven to be elliptic in shape (since the projection of any circle onto another plane is elliptic [6]). The projection geometry is shown in Figure 1.

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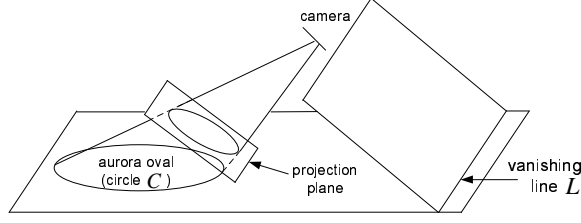
Figure 1. Illustration for projection of aurora oval onto UVI image

(a) (b) (c)
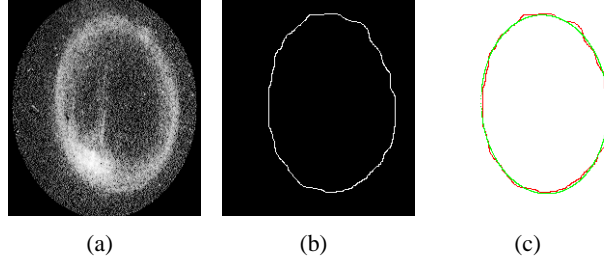
Figure 2. (a) Original image (b) Manually traced outer boundary (c) Fitted quadratic overlaid on outer boundary

2.2.1 Aurora Oval Shape Characteristic

Experiments were performed in the project to empirically confirm the theoretical results. The experiment involves manually locating the auroral arc's outer boundary in 50 UVI images and then fitting a general quadratic to those points using least squares. The general quadratic that was fitted is shown in Equation 1:

$$Ax^2 + By^2 + Cxy + Dx + Ey + F = 0 . \tag{1}$$

The quadratic's type can be determined by shape invariants, $\triangle$, J, and I [8]:

$$\triangle = \begin{vmatrix} A & C/2 & D/2 \\ C/2 & B & E/2 \\ D/2 & E/2 & F \end{vmatrix}, J = \begin{vmatrix} A & C/2 \\ C/2 & B \end{vmatrix}, I = A + B.$$

Specifically, if $\triangle \neq 0, J > 0$, and $\frac{\triangle}{I} < 0$, the quadratic is an ellipse [8].

Figure 2 shows an example of one of our experiments. In part (c), the manually traced boundary is shown in red and the fitted boundary is overlaid in green.

2.2.2 Developed Methodology

Thus, the auroral oval should be expected to be oval in UVI images. The method we have developed in the project exploits this shape. The method's basic processing scheme is shown in Figure 3.

We want to discuss only the ellipse detection part of the processing here. That processing is based on the Randomized Hough Transform (RHT) [7]. The RHT involves randomly selecting a few points in the image and using them to determine one likely set of parameters that describes the shape. RHT, like standard Hough, is a binning process that sets up a set of bins for each parameter. Each randomly

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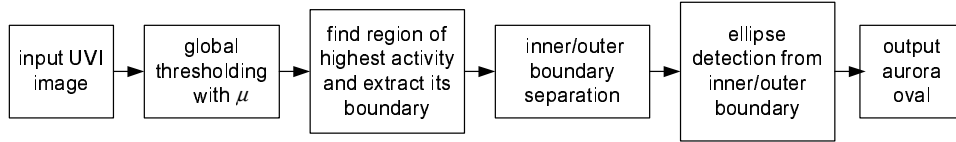
Figure 3. Shape-based aurora oval segmentation algorithm

(a) 99006_095020   (b)   (c)   (d)

(e)   (f)   (g)   (h)
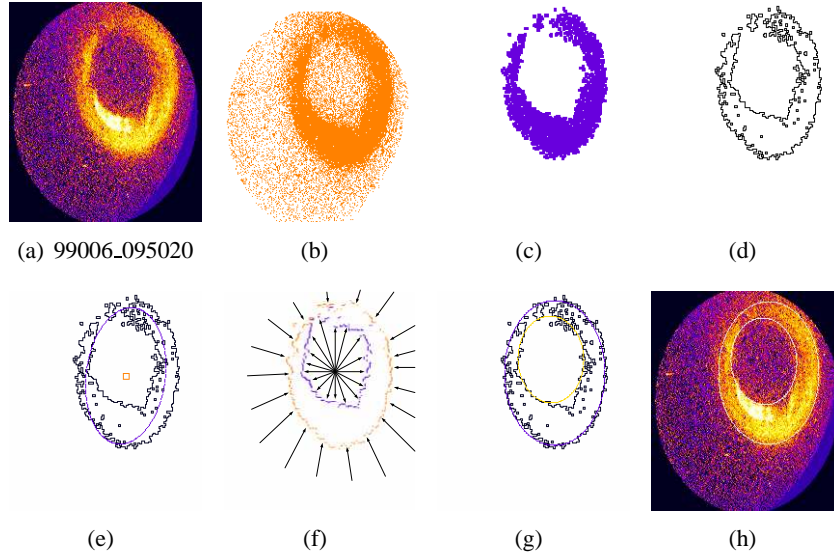
Figure 4. (a) Original image (b) Global thresholded result using μ (c) Dense part of (b) (d) Edge of dense part (e) Fitted ellipse to edge of dense part and its center (f) Radial based inner/outer boundary separation (g) Fitted ellipses to inner/outer boundary (h) Fitted ellipses overlaid on original image

selected set of points increments one of the bins. At the end of the process, the bin with the most votes is taken as the most likely parameterization of an ellipse.

An illustration of the processing steps for one image is shown in Figure 4.

2.2.3 Results So Far, in Brief

Some results of our method's application are shown in Figure 5

We have found the method we developed to be robust, even in the presence of various forms of image noise. In the future, we may be able to use the shape information determined from the localization process as features to support image mining based on shape.

One outcome of our RHT-based work, is that we have discovered that the methodology we use to find ellipses can be generalized to ellipsoid detection. That form of result for RHT was not previously known in the literature.

3 Plans for Remaining Time

The sub-project overseen by Co-I Hung at his university (SPSU) investigating improved k-means auroral arc localization methods did not begin until January 2005 due to paperwork processing delays

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(e) 99006_075007
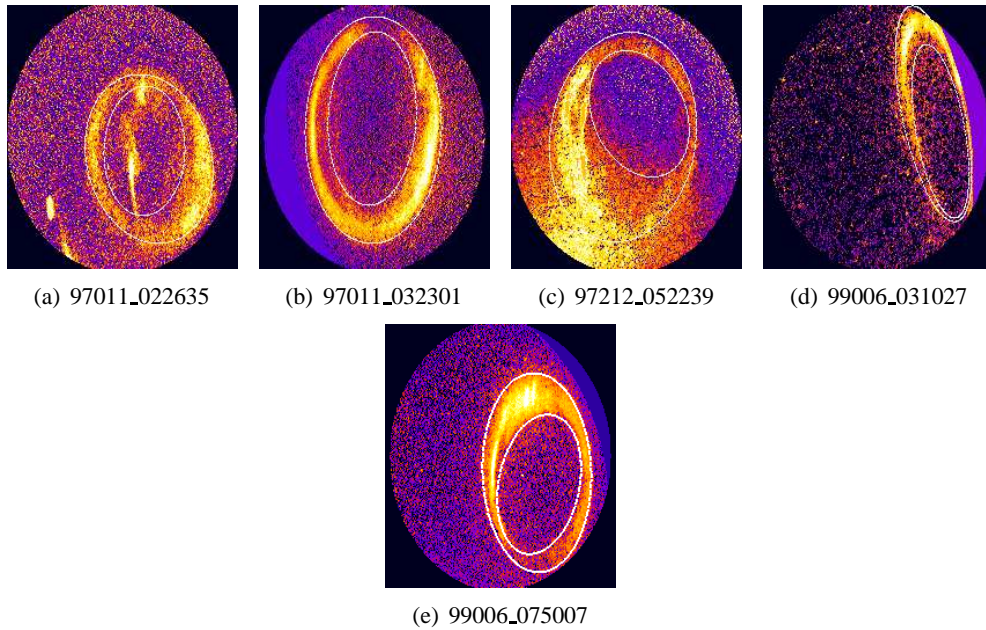
Figure 5. Some segmentation results

at UAH and SPSU. Dr. Hung was also on personal leave for most of the summer in 2005. Their component of the project will reach its conclusion during Summer 2006.

The key issues to be addressed in the remainder of the project are establishing the performance characteristics of the methods and beginning the process of incorporating them into the On-line Search Tool.

In the next few months, we aim to produce several publications related to project findings. First, we aim to present a paper that grew out of the AISRP investigation of detecting ellipses (i.e., the discovery that RHT-based processing can be used to locate ellipsoids) at the International Conference on Pattern Recognition in August 2006. We also hope to present a paper at a data mining or image retrieval conference in Fall 2006. A couple of journal papers are also in the works.

4 Contributions to Education

We also would like to note some educational outcomes arising out of the report. A Ph.D. student in Computer Science at the UAH has been supported by the project since January 2005. That student, Chunguang "Ken" Cao, is on-target to defend his Ph.D. dissertation in October or November of 2006. His primary activities on the project have been realization of the Hough-based methods guiding auroral oval localization. He is the first author of a poster describing progress on the work that was presented at the Fall 05 AGU. Mr. Cao's research capabilities dramatically improved as a result of his work on the project.

5 Final Words

The project is currently in a no-cost extension, and, baring an unforeseen calamity, we expect to conclude it during Summer 2006. The results we've produced are encouraging to us, and we look forward to the next report in which we should be able to report results of a study that establishes the level of performance achieved by the methods being developed.

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